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Linking farmer and beekeeper preferences with ecological knowledge to improve crop pollination

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Author contributions:
TB to GP and DK designed the study, analysed the data and wrote the first draft of the manuscript; all authors contributed data and revised the manuscript.

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Abstract

1. Pollination by insects is a key input into many crops, with managed honeybees often being hired to support pollination services. Despite substantial research into pollination management, no European studies have yet explored how and why farmers managed pollination services and few have explored why beekeepers use certain crops.
2. Using parallel surveys of beekeepers and farmers in 10 European countries, this study examines beekeeper and farmer perceptions and motivations surrounding crop pollination.
3. Almost half of the farmers surveyed believed they had pollination service deficits in one or more of their crops.
4. Few farmers hired managed pollinators, however most undertook at least one form of agri-environment management known to benefit pollinators, although few did so to promote pollinators.
5. Beekeepers were ambivalent towards many mass flowering crops, with some beekeepers using crops for their honey that other beekeepers avoid because of perceived pesticide risks.
6. The findings identify a number of opportunities for further collaboration between farmers and beekeepers and the knowledge gaps that need to be resolved.

Introduction

Pollination is a key ecosystem service in global crop agriculture, improving crop productivity in 75% of the world's significant crops (Klein et al., 2007), underpinning an estimated $235-577bn in annual production globally (IPBES, 2016) and supporting the supply of key micro-nutrients in human diets (Smith et al., 2015). In many regions, pollination services are primarily supplied by wild insects from the surrounding landscape (Garibaldi et al., 2013) and the demand for pollination services growing more rapidly than the supply of honeybees (Breeze et al., 2014), leading to increased reliance on declining wild pollinators (IPBES, 2016). However, managed insects are often key pollinators, particularly in large, homogenous landscapes, with the European honeybee (*Apis mellifera*) providing approximately half of recorded crop visits in European studies (Kleijn et al., 2015).

Many farming practices designed to enhance crop production have resulted in long-term pressures on the wild and managed pollinators required to maximise productivity (IPBES, 2016). For example, agricultural intensification generally leads to loss of non-crop forage habitat in the wider agricultural landscape, negatively influencing wild pollinators (Ricketts et al., 2008, Kennedy et al., 2013) and honeybee colony survival (Smart et al., 2016) and increasing pollinator reliance on mass-flowering crops for food resources (Holzchuh et al., 2016). Mass-flowering crops, however, only provide a pulse of food during the crop flowering period, resulting in a forage deficit in simplified landscapes (Peerson and Smith, 2013) and increase exposure to pesticides, potentially impacting on bee fitness at various scales (Rundlof et al., 2015, Tsvetkov et al., 2017 but see IPBES, 2016). These effects support evidence that, globally, growth in crop yields is negatively correlated with increasing crop dependence upon pollination (Garibaldi et al., 2011).

Scientific understanding of the relationships between farming practices, landscape composition and pollination services is increasing rapidly (IPBES, 2016). Comparatively less is known about the perceptions and knowledge base of the main stakeholders (farmers and beekeepers) within this system and how they make management decisions. In particular, little is known about the extent to which farmers perceive pollination service deficits (yield reductions due to inadequate pollination) and how they respond to these deficits (Hanes et al., 2013). Similarly, although there is some evidence that trade-offs between benefits (honey yields, pollination fees etc.) and costs/risks (management costs, low honey quality etc.) to beekeepers can affect decisions on hive placement

(Rucker et al., 2012; Lee et al., 2018), how these and other environmental factors affect hive placement Europe is largely unknown.

Understanding the perceptions of farmers and beekeepers can identify preferences, actions and knowledge gaps regarding the interrelations between honeybees and crop pollination, identify potential collaborations between the two stakeholder groups and assist in the formulation of effective actions. Here, we present results of two parallel Europe-wide questionnaire surveys that collectively explore (1) the use and avoidance of crops by beekeepers and their motivations for these decisions, (2) farmers' perceptions of pollination service deficits and their pollination management and (3) the collective views and incentives of both farmers and beekeepers on what can be done to bolster pollination services.

Methods

Surveys of farmers and beekeepers

Two separate quantitative surveys were designed, one for beekeepers and one for growers of insect-pollinated crops (hereafter, 'farmers'). After determining the core research questions, informal consultation with UK farmers and beekeepers was used to identify motivations for beekeepers using or avoiding crops or farmers used particular pollinators.

The farmer survey was initially tested by ten UK farmers or farm advisers, while the beekeeper survey was piloted by 54 members of the UK Bee Farmers Association in May and June 2015. Slight edits to the phrasing of some questions in both surveys were made in response to the pilot phase and final surveys were distributed between September 2015 and March 2016.

Both questionnaires had a similar format: asking respondents to name crops that they used and avoided (beekeepers) or used particular pollinators for (farmers). Once named, respondents were invited to select from number of reasons for their decisions. Additional, limited response, questions were posed to contextualise the responses from each group, for example whether or not beekeepers considered themselves professional or hobbyists. Finally, a series of open questions were used to gain further insight into what each group believed could be done to improve pollination service provision. Beekeepers were asked i) what factors would encourage them to manage more hives, and what ii) farmers and iii) policy could do to encourage them to provide more pollination services to crops. Farmers were asked to name interventions they would like to use to bolster pollination services and what was preventing them from doing so. The final surveys (appendix 1) were created and distributed in the online survey software Qualtrics. All responses were recorded anonymously, identified only by a unique number. The questionnaire was approved by the ethics committee of the University of Reading.

The survey was translated into the appropriate language and distributed in 21 European or European Near Neighbour countries (Table 1). Surveys were widely distributed through farmer networks, beekeeper and farmer associations and blogs, and in some countries also through targeted media outlets with reminders sent out approximately a month after the initial send. Effort was made to promote the farmer survey to both horticultural and arable farmers as honeybees are typically more widely used in permanent crop systems but the study aimed to capture a wider plurality of views.

Results were translated back into English by native speaking co-authors. For each country, survey response data were only included in analyses where there were at least 20 responses to both the beekeeper and farmer survey. This threshold resulted in a final dataset from ten countries (Table 2) largely due to low responses from farmers. Responses to the open questions were reviewed and grouped together based on keywords (see Annex 7 for full results).

Table 1: Countries and languages in which the survey was distributed

Country	Language(s)
Belgium	French, Dutch
Bosnia and Herzegovina	Bosnian (Cyrillic and Latin)
Croatia	Croatian
Cyprus	Greek
Czech Republic	Czech
Estonia	Estonian
Germany	German
Greece	Greek
Hungary	Hungarian
Ireland	English
Israel	Hebrew
Italy	Italian
Malta	English, Maltese
Netherlands	Dutch
Poland	Polish
Portugal	Portuguese
Serbia	Serbian
Slovakia	Slovakian
Slovenia	Slovenian
Spain	Spanish
UK	English

Table 2: Response numbers from countries used in the analysis

Country	Beekeepers	Farmers
Cyprus	31	32
Estonia	104	59*
Greece	193	21
Italy	196	58
Malta	38	39
Netherlands	191	32
Portugal	150	57
Slovenia	320	29
Serbia	134	41
UK	352	58
Total	1708	406

*In total over 500 farmers in Estonia responded to the questionnaire. To prevent this from dominating the response set, a random sub-sample of 59 farmers was selected for use in the analysis, equal to one greater than either the UK or Italy (jointly the next highest scoring countries). In addition, to prevent the sample being heavily weighted towards farmers who did not name crops, the random sample of Estonian farmers was stratified by an average of the number of UK and Italian farmers who had listed 0, 1, 2 and 3 crops.

In some cases, crop types were merged into a single category for analytical purposes. For example, cherry, sweet cherry and sour cherry were merged into the category “cherry” as many respondents had not specified which species they were using. Duplicate responses, where a single respondent repeatedly named the same crop to answer the same question (crop used, crop avoided or crop requiring pollination) were also removed.

Synthesis of empirical data on crop pollination in Europe

Data on total planted crop area (in hectares per country) across Europe were collected from the FAO statistical database (FAOSTAT, 2019a) for the year 2015, the most recently available data at the time of analysis. Orchard crop area was not available and was not estimated due to differences in the use of the term "orchard" in different countries (including or excluding citrus or olives for example). For some crops (chestnut) these data were absent and hence correlations between use and avoidance were not conducted. Due to the insufficient sample size of farmers in some countries, no statistical analysis could be conducted to draw any meaningful trends.

Statistical Analysis

Statistical analyses were conducted in R version 3.2.0 using the base packages (R Core Team 2018). Tests of differences between binary beekeeper and farmer background questions (e.g. professional vs hobby beekeeper) between countries were conducted using pairwise Kruskal-Wallis tests. Correlations between i) beekeeper years of experience and number of hives, ii) farmers' perceived pollination service deficits and maximum extent of yield loss without pollination and iii) between crop use/avoidance and total planted crop area (across all countries) were explored using Spearman's Rank correlation analysis.

Results

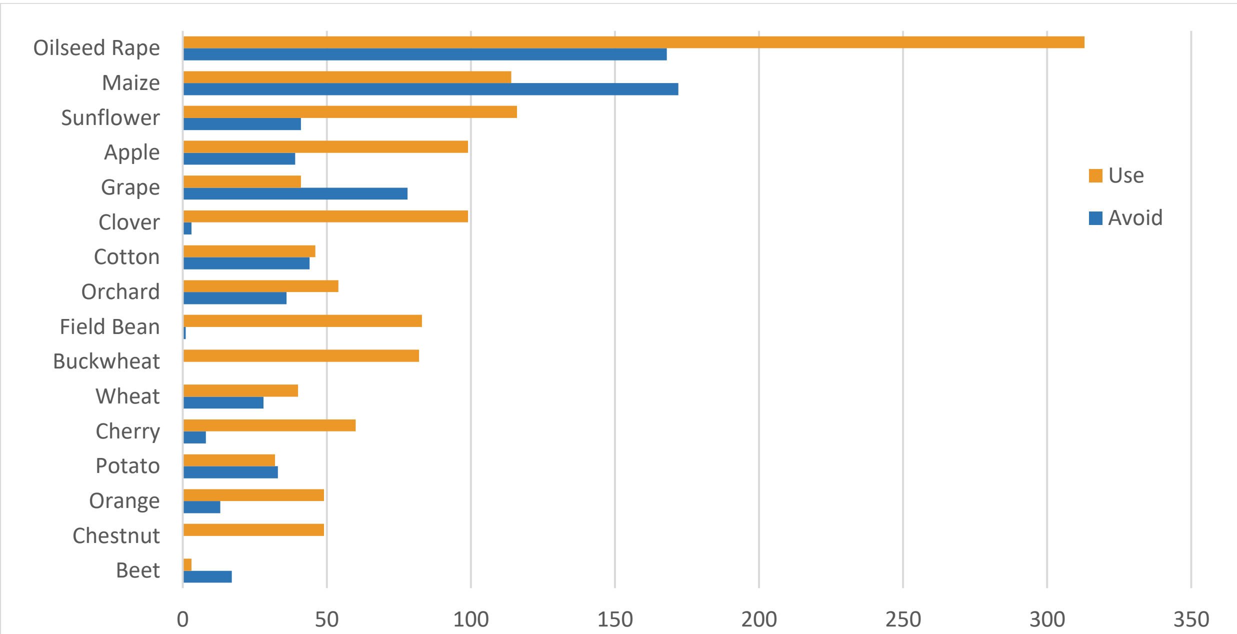
In total, 1708 beekeepers and 426 farmers from ten European countries provided usable responses (Table 2). Of the beekeepers, 71% identified as hobbyists and 29% as professionals (Appendix 2). Respondents managed on average 71.5 (s.d.±152) hives each and have kept bees for an average of 14.3 (s.d.±14.2) years. Professional beekeepers (n=488 had significantly more years of beekeeping experience (χ^2=221.22, d.f.=59, $p<0.001$) and kept significantly more hives than hobby beekeepers (χ^2=972.22, d.f.=131, $p<0.001$). Years of beekeeping experience was positively correlated with hive number (ρ =0.436, d.f.=1706, $p<0.001$). As expected, the number of hives managed varied significantly between countries, with Cypriot, Portuguese and Greek beekeepers managing more colonies per beekeeper than most other countries (Chauzat et al., 2013). Between country differences in beekeeping experience were largely non-significant (Appendix 2). At present there is no Europe wide census of beekeeping activities, with individual countries instead collecting different data, making comparison difficult. Compared with 2010 data compiled by Chauzat et al., (2013), professionals represent a greater than expected proportion of respondents but have a lower than expected number of hives/beekeeper (Appendix 2). This may be due to inconsistencies between beekeepers who identified as professional or those that are classified as such, although this definition varies between countries (Chauzat et al., 2013).

Among the farmers, 17% practiced organic farming, 11% took part in agri-environment schemes (AES) and 8% practised both. Statistics on the number of farmers in agri-environment schemes are not available. The sample over-represents organic farmers who account for ~3.4% of farmers in the surveyed countries (EUROSTAT, 2019), likely due to the channels the survey was distributed through. The relatively low response rate of farmers is not atypical for online surveys and the survey's particular niche subject is likely to have increased self-selection bias towards farmers who actively consider pollination.

Use and avoidance of crops by beekeepers

Beekeepers identified 101 crops (including crop groups) that they used and 80 that they avoided. There was significant overlap between the two groups with five of the eleven most commonly used crops being also among the ten most avoided crops (Figure 1). However, few individual beekeepers listed the same crop as both used and avoided, with the exception of Maize, where 24% of those who used the crop (n=114) also wished to avoid it. Of the beekeepers using and avoiding maize, 62% indicated that they moved their hives within the year. By contrast, chestnut and buckwheat were widely used but not avoided by any beekeeper. At country-specific level crop use was significantly correlated with planted crop area (ha/country), in buckwheat (ρ=0.975, d.f.=8, p=0.005) and sunflower (ρ=0.929, d.f.=8, p=0.006). By contrast, crop avoidance by country was significantly correlated with planted crop area in apple (ρ=0.778, d.f.=8, p=0.023), oilseed rape (ρ=0.883, d.f.=8, p=0.003), grape (ρ=0.827, d.f.=8, p=0.006), potato (ρ=0.747, d.f.=8, p=0.033) and sunflower (ρ=0.939, d.f.=8, p<0.001).

Figure 1: Summary of the main crops used (orange) and avoided (blue) by beekeepers. The crops represent the 12 most commonly used (due to tied values) and 10 most commonly avoided across all 1708 respondent beekeepers.



When asked for reasons why they use or avoid crops, beekeepers (Table 3) indicated that honey yield (50% of responses), crop accessibility (49% of responses), crop availability (46% of responses) and importance for colony growth and survival (43% of responses) were the main factors driving crop use. Payment for pollination services was only a factor influencing crop use in 18% of responses, primarily in the Netherlands, Serbia and the UK, for oilseed rape, sunflower and apple, respectively.

Concern over pesticide exposure was the primary reason to avoid a crop (Table 4, 74% of responses), followed by concerns over the toxicity of the nectar to bees and humans (30% of responses). Other factors, including a lack of payment, were only listed in 11% of responses across all crops.

Table 3: Summary of reasons why beekeepers use crops

Crop	N	Yield	Quality	Access	Available	Sustain	Recommended	Paid	Own	Growth	Reliable
Apple	99	28%	13%	42%	42%	28%	6%	26%	24%	44%	24%
Buckwheat	82	56%	43%	50%	50%	67%	18%	7%	24%	59%	34%
Cherry	60	42%	18%	47%	45%	55%	8%	28%	18%	58%	25%
Chestnut	49	67%	63%	47%	57%	51%	27%	2%	24%	43%	51%
Clover	99	62%	45%	58%	47%	41%	8%	5%	17%	53%	51%
Field Bean	83	70%	40%	65%	36%	37%	4%	22%	5%	55%	36%
Maize	114	7%	5%	24%	12%	11%	1%	2%	8%	13%	5%
Oilseed Rape	313	73%	19%	58%	71%	41%	12%	16%	3%	57%	52%
Orange	49	71%	51%	57%	55%	47%	16%	2%	16%	59%	47%
Orchard	54	33%	24%	37%	41%	35%	13%	26%	20%	43%	15%
Sunflower	116	73%	32%	61%	46%	37%	47%	37%	8%	22%	11%
All crops		**50%**	**30%**	**49%**	**46%**	**37%**	**13%**	**18%**	**13%**	**43%**	**32%**

N: Number of respondents across all countries that listed this crop as one they used. Yield: the crop has a good honey yield. Quality: the crop produces a high-quality honey. Access: the crop is easily accessible. Available: the crop is widely available within the landscape. Sustain: the crop is important to sustain colonies. Recommended: the use of the crop was recommended by another beekeeper. Paid: the beekeeper is paid to provide pollination services to the crop. Own: the beekeeper also owns the crop and wants it to be pollinated. Growth: The crop is important for colony growth. Reliable: the crop produces reliable honey yield. 11 crops were selected as equal numbers named orange and chestnut. Orchard denotes unidentified orchard crops.

Table 4: Summary of reasons why beekeepers avoid crops

Crop	N	Yield	Unreliable	Quality	Alternatives	Toxic	Pesticides	No pay	Recommended	Disease
Apple	39	8%	8%	3%	13%	31%	69%	10%	13%	3%
Beet	17	18%	0%	0%	12%	0%	71%	12%	6%	18%
Cotton	44	9%	14%	18%	18%	16%	73%	16%	16%	9%
Grape	78	24%	12%	8%	15%	27%	91%	5%	12%	8%
Maize	172	22%	12%	12%	15%	35%	80%	8%	10%	5%
Oilseed Rape	168	4%	6%	36%	20%	21%	61%	18%	5%	4%
Orchard	36	0%	14%	11%	6%	44%	83%	11%	6%	0%
Potato	33	21%	21%	18%	21%	21%	85%	9%	6%	12%
Sunflower	41	29%	29%	17%	22%	63%	78%	17%	15%	20%
Wheat	28	43%	11%	14%	21%	18%	71%	7%	7%	7%
All Crops		**17%**	**12%**	**16%**	**18%**	**30%**	**74%**	**11%**	**9%**	**8%**

N: Number of respondents across all countries that listed this crop as one they avoided. Yield: the crop has poor honey yield, unreliable: the crop produces unreliable honey yields. Quality: the honey produced from the crop is of poor quality. Alternatives: there is better alternative forage available at the same time of year. Toxic: the nectar is toxic to bees or humans. Pesticides: the crop has an unacceptable risk of pesticide exposure. No Pay: the beekeeper is not paid for pollinating this crop. Recommended: other beekeepers have advised that this crop should be avoided. Disease: the crop has an unacceptable risk of bringing hives into contact with pests or diseases. Orchard denotes unidentified orchard crops.

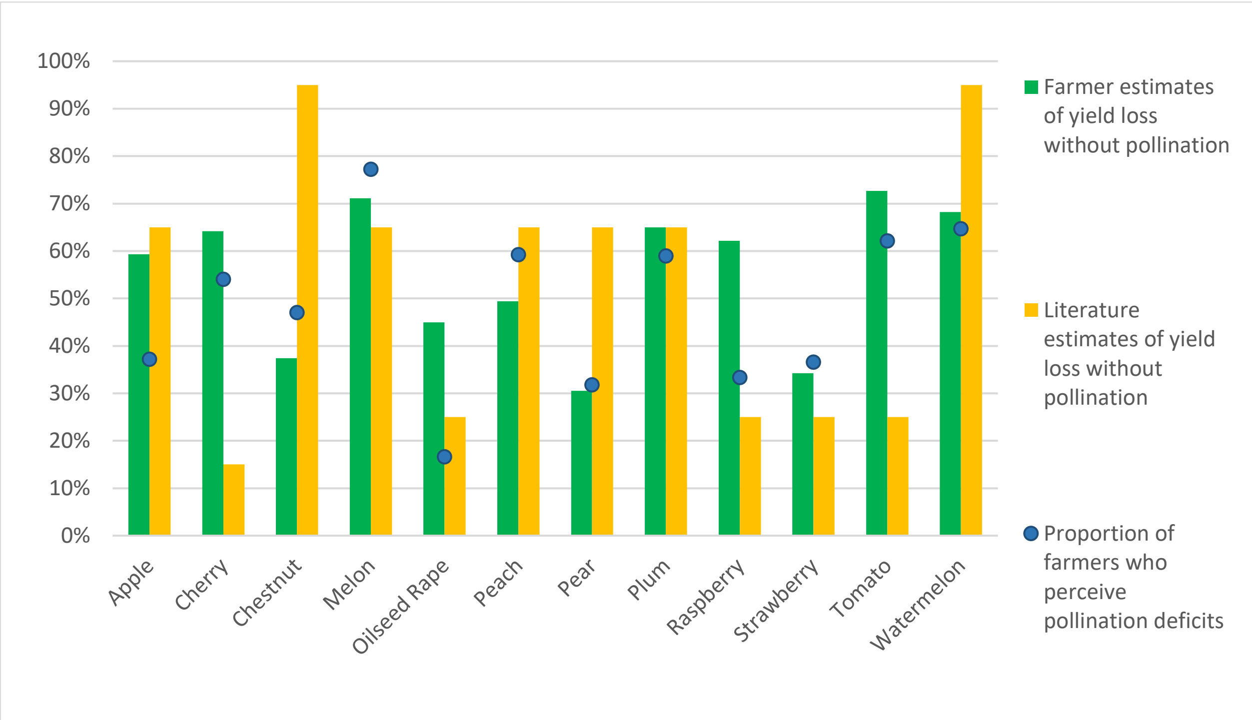
Farmer perception of pollination service deficits and pollination management

Farmers named 106 crops which they grew and believed require insect pollination (Appendix 2). Of these, only 3 crops were grown by ≤10% of respondents: apple (18% of respondents), oilseed rape (13%) and strawberry (10% of respondents). Of the 12 most widely named crops (minimum: 17 responses), only five were among the 12 most widely used by beekeepers, and only three among the

10 most avoided. In particular, soft fruits and unspecified "orchards" were more frequently named by farmers as requiring pollination services than named by beekeepers as used or avoided crops.

Approximately 49% of farmers indicated that they experienced yield deficits due to inadequate pollination (pollination deficits) in at least one crop they grew (Appendix 3). Of these, ~56% (n=68) hired one or more managed pollinators. Farmers' perceptions of yield dependence upon insect pollination often differed substantially from literature estimates (Klein et al., 2007), including three crops where yield loss estimates were >20% lower (watermelon, chestnut and pear) and two crops where estimates were >20% higher (raspberry, tomato) than literature medians (Figure 2).

Figure 2: Farmers' perceived yield loss in the absence of pollination services compared with literature estimates (from Klein et al., 2007) and percentage of farmers who perceive pollination service deficits, arranged by crop



In terms of pollination management, 31% of farmers indicated that they own honeybees, 29% hire one or more pollinating taxa (in total, 47% either owned or hired at least one managed pollinator) and, despite few farmers partaking in agri-environment schemes (AES), 64% use one or more of three environmental management measures: flower rich field margins (29%), avoid spraying at field margins (low input margins) (51%) and hedgerows (40%). In Estonia, Portugal, Italy and Serbia, >25% of respondents owned their own honeybees compared with <10% of respondents in the Netherlands, UK or Greece (Appendix 4). Serbian farmers accounted for almost half (48%) of managed solitary bee use, on several crops. Enhancing pollination was not often mentioned as a reason for using environmental management measures, both across all crops pooled and individual crops (Appendix 5).

Farmers' of management decisions were mostly driven by effectiveness (managed honeybees and bumblebees), recommendations from other farmers (solitary bees) or improving yield through means other than pollination services (environmental management) (Appendix 5). Using an ordinal 0-5 scale of pollinator effectiveness per crop, farmers believed that honeybees were the most effective source of pollination services (median score 5), followed by agri-environment measures (median score 4), managed bumblebees (median score 4) and managed solitary bees (median score 3). At a crop specific level, honeybees had the highest or joint-highest median effectiveness scores in 10 of the 12 most common crops. Of the other crops, bumblebees had the highest effectiveness score for melon (median 4) and solitary bees for pear (median 4.5). In watermelons, all measures had an equal median score of 5 (Appendix 6).

Views on incentives to support honeybees and enhance crop pollination services

Each questionnaire ended with a number of optional open questions. As expected, these have lower response rates than other questions, however in all cases professional beekeepers provided a similar proportion of answers to amateurs. Common factors that beekeepers suggested would incentivise them to increase the number of hives they keep from current levels include: improved honey yield (n=140, 8% of respondents), greater forage availability to sustain colonies (n=111, 6% of respondents) and stronger honey markets (n=102, 6% of respondents) (Appendix 7). For beekeepers, reducing pesticide exposure was the most commonly suggested measure that both farmers (n=400, 23% of respondents) and policymakers (n=140, 8% of respondents) could undertake to support increased honeybee pollination services, although few beekeepers suggested banning some or all pesticides (n=20, 1% of respondents as a farmer action and n=65, 4% of respondents as a policymaker action). Greater farmer willingness to pay for pollination services (n=158, 9% of respondents), policymakers introducing subsidies for pollination services (n=122, 7% of respondents) and increasing awareness of beekeeper pollination services (n=135, 8% of respondents as a farmer action and n=118, 7% of respondents as a policymaker action) were also commonly suggested. Professional and hobby beekeepers gave similar answers to most questions. Hobbyists made up a disproportionate majority of respondents wanted greater forage availability in order to manage more hives (82 of 111) or (if provided by farmers) provide more pollination services (102 of 115). This difference is driven by the large number of hobbyists who do not move their hives. Hobbyists also made up a majority of those who wanted policymakers to ban one or more pesticides (47 of 65).

Farmers most frequently listed hiring honeybees (n=19, 6% of respondents), bumblebees and increasing on-farm flower abundance and diversity (both: n=11, 4% of respondents) as measures they would like to implement in the future, but citing lack of experience (68% with honeybees, 64% with bumblebees) and expenses (60% with flower abundance and diversity) as the main barriers.

Discussion

Despite the benefits of pollination to high-value crop systems (IPBES, 2016), the perceptions of farmers and beekeepers on pollination management have been largely overlooked. This study used parallel surveys across ten European countries to compare beekeeper use of crops with farmer demands for pollination services. The findings highlight opportunities for further co-operation between beekeepers and farmers as approximately half of the farmers surveyed believed they were experiencing pollination deficits (yield losses due to inadequate pollination). Many beekeepers used mass-flowering crops due to their accessibility and high honey yields, but there was widespread crop avoidance due to pesticide exposure. By identifying such barriers and knowledge gaps, wider collaboration between these two key stakeholders can be developed.

Beekeeper crop use and avoidance

Beekeepers, as a group, were ambivalent about utilising flowering crops, with some beekeepers preferring to utilise certain crops while others preferring to avoid these very same crops (Figure 1). This results from beekeepers perceiving different trade-offs between the benefits of using these crops as forage (mainly honey yield, access and availability) and the perceived costs, primarily the risks of exposure to pesticides. Oilseed rape and sunflower were widely used by beekeepers for their honey yields and resources, while at the same time widely avoided by others primarily because of perceived pesticide risk. Research into pesticide impacts on honeybee colonies has produced mixed results, from no impact to moderate effects on short-term colony functioning (IPBES, 2016; Tsvetkov et al., 2017, Woodcock et al., 2017; Holder et al., 2018), and therefore fails to provide clear guidance to beekeepers. Furthermore, despite these concerns, field beans and buckwheat were widely used and rarely avoided, suggesting that these crops are perceived as relatively safe, despite often being treated with insecticides and potentially being cross contaminated by metabolites from previous treatments in a rotation (Botias et al., 2016). Professional and more experienced beekeepers were also less likely to avoid crops because of pesticide risks. Collectively, these findings indicate that, lacking clear advice from empirical research beekeepers judge the risks of pesticides from their own experiences and other sources (e.g. the media).

Use of crops was most often driven by honey yield potential, accessibility or the time of the year the crop flowered. Literature on nectar and honey production is sparse, although generally those crops that were used for nectar by a high proportion of beekeepers tend to have a greater quantity and concentration of nectar than other crops (notably buckwheat, sunflower and oilseed rape – Free, 1993). For many crops listed, the total concentration of nectar has not been studied, notably chestnut which many beekeepers used but only one avoided. However, a small number of hobby beekeepers indicated that they used crops which bear no nectar (e.g. maize) because they are good sources of honey. These findings indicate that beekeepers use personal experience rather than scientific literature to determine the honey yield of a crop. Therefore, further research into how different beekeepers perceive trade-offs between honey yield and pesticide risk will be a key step in fostering co-operation with farmers growing high-yielding crops.

Farmer perceptions of pollination services

Approximately half of the sampled farmers believed they had a pollination deficit (yield shortage due to inadequate pollination) in one or more of their crops. The crops that were most widely identified as experiencing pollination deficit (e.g. melon/watermelon, tomato) are not ones that beekeepers tended to favour or avoid. This may be partially due to the specialised nature of many farmers, where they predominantly grow one or only few different crops, compared to beekeepers who can place their hives in several different cropping systems to take advantage of optimal nectar resources. While pollination deficits have been reported in particular case studies (e.g. Garratt et al., 2014), it is impossible to estimate how widespread such deficits are without extensive monitoring of pollination services (e.g. Carvel et al., 2016). Pollination deficits often manifest in obvious ways on crops such as strawberries (greater proportion of malformed fruits – Klatt et al., 2014), but in many other crops (e.g. oilseed rape) this could be conflated with deficits in other areas, such as pest regulation (Lundin et al., 2013). These findings point to an urgent need for widespread monitoring of pollination services to inform farmers and effectively allocate resources to areas that are experiencing, or are at high risk of, pollination deficits.

Despite the widespread perception of pollination deficits, few farmers actively hired managed pollinators, possibly due to a lack of clear-cut information on pollination management available to farmers. Most recommendations on the number of hives per hectare to achieve optimal pollination of a particular crop are based on expert judgement rather than primary research (Rollin and Garibaldi, 2019). Although, studies generally demonstrate linear relationships between crop yield and pollinator visitation (Klein et al, 2003), this relationship is likely to reach a saturation point where all plant ovules are fertilized (Morris et al., 2010) and excessive pollination damage economic output in some crops (Garratt et al., 2014; Saez et al., 2014). Consequently, the relationship between managed pollinator density and yield is unlikely to be linear in many crops and will require specific studies to determine efficient honeybee use.

Many farmers used one or more of three agri-environment management measures (hedgerows, flower rich field margins and low input margins). Both hedgerows and flower-rich field margins are particularly beneficial environmental management measures for pollinators, even in already diverse landscapes (Scheper et al., 2013), and may therefore can enhance productivity (Blaauw and Isaacs, 2014, Pywell et al., 2015). This, along with the high average rating for pollinator effectiveness, suggests that farmers recognize the benefits of these management options, despite pollination services not being the main motivator behind habitat creation. Farmers therefore appear to view pollination as a low priority, focusing instead on managing for what they perceive as more pressing issues, such as soil quality (Zhang et al., 2018a). However, research increasingly suggests that yields of pollinated crops are limited by inadequate pollination (Garibaldi et al., 2011) and pollination is at least as important as conventional inputs (Fijen et al., 2018), further highlighting the need to better examine the actual importance of pollination services across Europe.

In five of the 12 most commonly named crops, farmers' estimated yield loss in the absence of pollinators differed by more than 20% to literature estimates. However, the literature base is also small, not standardised and often old for many crops. More recent studies have demonstrated that the impact of pollination on crop yield differs between varieties (Garratt et al., 2016; Hudewenz et al., 2013), local landscape context, and interactions with other inputs (e.g. Lundin et al., 2014). Although they are unlikely to be based on empirical methods, farmers' perceptions may possibly more accurately reflect current, local conditions. However caution should be exercised in interpreting these perceptions for niche crops as a small number of farmers also believed that wind pollinated crops (e.g. 13 farmers named wheat as a pollinated crop). Standardised field studies (Carvel et al., 2016; Garratt et al., 2016) exploring pollinator dependence of current and emerging varieties, in relation to other inputs and landscape context, would allow for researchers and agronomists to provide better advice on pollination management.

Future collaborations: Reducing Pesticides

Reducing, but not banning, pesticide use was the most widely suggest farmer and policy action among professional and hobby beekeepers. Presently, European farmers typically use insecticides to pre-empt pest damage rather than directly control outbreaks (Ahmed et al., 2011; Zhang et al., 2018a). The EU's recent restriction on neonicotinoid insecticides (European Commission, 2018), which are typically applied before seeding arable plants, is likely to cause farmers to revert to older compounds (e.g. phyrretheroid sprays- Zhang et al., 2017), which have not been as rigorously assessed for their impact on pollinators (IPBES, 2016). An alternative is integrated pest management (IPM), where farmers encourage natural enemies of pests within their fields and only apply insecticides when pest densities reach a certain threshold, reducing exposure of non-target pests and potentially saving farmer costs (Zhang et al., 2018b). Furthermore, despite evidence for the effectiveness of lower chemical use in supporting pollinator populations (Scheper et al., 2013), the surveyed farmers who used low input field margins were more likely to perceive pollination deficits and rarely indicated that they used this management to improve pollination services.

Uptake of change is slow because farmers often do not perceive benefits from natural enemies (Zhang et al., 2018a), and are concerned that neighbouring farmers will not fully co-operate (Stallman and Jones, 2015), increasing the risks of their fields being a safe haven for pests (Wilson and Tisdell, 2001). Enhancing uptake will therefore require dedicated efforts to translate research into practical activities by focusing on outcomes that are relevant to farmers at a local scale (Kleijn et al., 2019). This evidence base can then be developed into programmes that, ideally, are demonstrably effective, trustworthy and with low initial risk (e.g. through no-cost trials) (Reed et al., 2014).

Future Collaborations: Developing Pollination Markets

Although few beekeepers indicated that payments received were a reason for using a crop, beekeepers widely stated that payments for pollination services would be a major incentive. Such markets for pollination services are relatively small in Europe, often run by beekeeping associations and with no centralised price or membership information available. American style large-scale migratory pollination markets, with beekeepers migrating between countries is theoretically possible. However, in Europe there is no single highly concentrated crop market on the scale of the California almond market (FAOSTAT, 2019a) upon which the profitability of the US pollination market depends (Lee et al., 2018; Ferrier et al., 2018). Other factors such as different standards for bee health and training between countries, (Chauzat et al., 2013) and the large number of languages in Europe (compared to the United States where English is the majority language) would also complicate such international markets. Instead, expanding national markets may be more viable.

Aside from the presence of a high demand crop, the viability of pollination markets are dependent upon a combination of: i) the availability of suitable forage for colony survival and honey production outside of crop flowering, ii) the market price of honey iii) the level of pollination service payments (Lee et al., 2018; Champetier et al., 2015). If suitable forage is not available, supplemental feeding, has a cost to both beekeeper profits and colony fitness, reducing the value of the colony as a unit of honey and pollination production in the future (Champetier et al., 2015). Such additional forage can be provided through dedicated in-field planting (flower margins), crop diversification or habitat maintenance (Cole et al., 2017), which are supported by agri-environment schemes in some of the countries surveyed (Baraty et al., 2015). However, while forage increases were widely suggested by beekeepers as a means to increase service provision, most of these were hobbyists, indicating that forage constraints are not a problem for professional beekeepers.

Increases in honey prices/profits and payments for pollination services were widely cited by professional beekeepers as factors that would encourage them to expand their stocks. Honey prices are heavily influenced by international trade with low cost imports often contributing to gradual reductions in domestic honey prices (Lee et al., 2018). As of 2015, four of the countries surveyed ((UK, Italy, Netherlands and Cyprus) import more honey than they produce, primarily from China, (domestic honey data absent for the Netherlands and Malta) (FAOSTAT, 2019a,b). In these countries, simple market controls such as tariffs may affect domestic honey prices, but more significant interventions such as subsidies may be required to increase honey profits in other countries.

Increasing payments for pollination services will require farmers to be willing to pay beekeepers profitable sums (Champetier et al., 2015; Breeze et al., 2017), believe it is important (Zhang et al., 2018a) and believe this is more viable than alternative measures (e.g. growing pollinator independent crops) (Ferrier et al., 2018). Such an economy could arise naturally through increased dialogue and barter between farmers and beekeepers. However if government or other third party intervention is required then prices should be based on the demonstrable economic benefits of additional bee hives against the full costs of supplying and managing hives all year round (Champetier et al., 2015; Lee et al., 2018) and address issues of free riding, whereby farmers may receive pollination benefits from hives hired by other farmers (Asare et al., 2017).

Subsidies, another measure widely suggested by professionals, may provide a solution to these problems. Currently, each EU country receives ~ €4.3/hive in support for beekeeping related issues, but not support for pollination services and of the countries surveyed, only Greece, Italy and Cyprus spend any of this subsidy on supporting local honey production (Majewski, 2017). Expanding these funds to subsidise e.g. providing services to low nectar crops, could expand commercial pollination without rising farming costs. Regardless of how it achieved though, any expansion of beekeeping markets should be mindful of potential negative impacts on wild pollinators (Lindstrom et al., 2017) and the potential health impacts of bee colony movement (IPBES, 2016).

Shortcomings and knowledge gaps

Although efforts were made to capture as broad a range of beekeepers and farmers as possible, the sample is biased towards organic farmers and professional beekeepers. The latter is less of an issue as amateurs typically own only a minority of national hives (Chauzat et al., 2013) and are less likely to provide pollination services (Breeze et al., 2017). However the limited farmer response, makes interpreting national scale trends and the appropriate responses very difficult.

Interpretation of these results is further hindered by a lack of statistical information on apiculture (hobby and professional) in each country, with only ad hoc data available (Majewski, 2017; Chauzat et al., 2013). Collecting this data in a regular, open and consistent manner should be a priority to underpin further research into apiculture across Europe and properly target initiatives and resources. Secondly, the findings highlight an urgent need to better understand how the perceptions of farmers and beekeepers around crop pollination are formed through further social science work building on this study. Understanding this will be essential to tailor research on e.g. pesticide spraying regimes, hive numbers or hive placement into practical outcomes (Kleijn et al., 2019). Finally, the study demonstrates that efforts to facilitate communication between farmers and beekeepers would be valuable to support pollination service security into the long term.

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Appendix 1 – Surveys

This appendix contains MS word versions of the two surveys. Note that not all questions were used in the analysis presented in the main study. In both beekeeper and farmer analysis, the crops/plants named are piped into the columns or rows of other questions (Q11-14 in the beekeeper survey, Q6-11, 13-15, 18, 21 in the Farmer survey), meaning that the responses are directly linked with those crops.

Several questions were only displayed/asked if other questions were answered in particular ways. These are denoted by text highlighted in blue.

If readers would like a copy of the survey in any of the languages indicated in Table 1 of the main manuscript, please e-mail t.d.breeze@reading.ac.uk. Readers are welcome to re-use part/all of this survey but please cite this publication as a reference for the basis. It is recommended that reproduction of these questionnaires take account of the issues identified below and use some of the responses in the open questions (Appendix 7) as fixed choices instead of the open questions posed in this version.

Despite pilot testing, some questions were consistently answered in an unsatisfactory manner. Several beekeepers named uncultivated plants in Q7, presumably because some beekeepers consider crop plants as those plants that provide nectar for honey. As such, plants that are not cultivated for consumption, ornamental use or seed (e.g. Phacelia sp.) were removed from this analysis. Similarly, cultivated crops (e.g. oilseed rape, apple, sunflower) listed by beekeepers as non-crop plant that they used (Q9) or avoided (Q10) were added to the analyses. In the cases of borage, thyme, blackberry (and unspecified Rubus sp.), lime (Robina sp.), clover and chestnut, these crops were only counted in the crop list if the beekeepers indicated that they received payments for pollination services, to distinguish between cultivated and uncultivated plants. Q9 and Q10, as well as the follow up Q14 and Q15 are not used in this analysis. In Q12, there was a very strong overlap between beekeepers who indicated that they avoided a crop because it's nectar was toxic and because they believed it had an unacceptable risk from pesticide, indicating that they are conflating the two responses.

In the farmer survey, Q10 and Q11 were regularly answered inadequately, with farmers often citing the total number of managed pollinators they hired/bought and/or the total amount they paid for them rather than the numbers on a per hectare basis. This made it impossible to estimate how much farmers are typically paying for their managed pollinators.

SUPER-B Beekeepers Survey

Thank you for agreeing to participate in this survey conducted by The University of Reading. The survey should take less than 20 minutes to complete. The purpose of this study is to find out what crops and flowering plants that beekeepers across Europe prefer to put their hives next to and why. We hope the findings of this study will inform future policy on wider countryside management to help beekeepers sustain their colonies. The findings will be published in a peer-reviewed academic journal, which we will endeavor to make openly available for any who are interested, and presented at beekeeping conferences. This study is funded by the EU's SUPER-B program, and has been designed, administered and will be analyzed by the University of Reading (UK).

Ethics Before we begin, we are required to explain a few details of this study. All information will be kept strictly confidential and none of the questions will allow you to be identified in any way. Should you wish to withdraw your answers from this survey at any time prior to the publication of results please call me on 0118 378 6419 or e-mail t.d.breeze@reading.ac.uk and quote the questionnaire ID below – this number is linked to your responses but the survey does not collect your personal details so it will remain anonymous. Your response will be held in our records for a period of no longer than 5 years and will not be passed on to any third parties. By participating you are consenting to these terms of data storage and use which have been approved by the University of Reading's Ethics Committee.

Q1 Please enter a number to identify this questionnaire (e.g. the date and time you are taking the survey)

Q2 Which country are you based in?

Q3 Would you consider yourself to be a professional beekeeper or a hobby beekeeper?
- ❍ Professional Beekeeper (1)
- ❍ Hobby Beekeeper (2)

Q4 Approximately how many years have you been keeping bees?

Q5 Approximately how many honeybee colonies do you presently manage?

Displayed if: “Would you consider yourself to be a professional beekeeper or a hobby beekeeper?” Professional Beekeeper Is Selected

Q3b Approximately what proportion of your beekeeping income do you receive from the following activities (you will not be asked to state your beekeeping income in any part of this questionnaire)?

______ Honey Production (1)
______ Pollination services to crops (2)
______ Other (e.g. Wax, breeding queens etc.) (3)

Q6 Do you move your hives at different times of the year?
- ❍ Yes (1)
- ❍ No (2)

Displayed if “Do you move your hives at different times of the year?” Yes Is Selected

Q6b What habitat (e.g. grassland, cropland, garden) do you typically place your hives in during the following months?

Spring (1)
Summer (2)
Autumn (3)
Winter (4)

Q7 If your hives are typically placed near (within 1km) any crop plants at any point in the year, which are the three crop plants they are most often placed by? (please leave blank if this does not apply)

Crop 1 (1)
Crop 2 (2)
Crop 3 (3)

Q8 Are there any crops you would rather avoid placing your colonies near (within 1km)? (please leave blank if this does not apply)

Crop 1 (1)
Crop 2 (2)
Crop 3 (3)

Q9 Aside from crops, what the three plants do you most prefer to place your hives near (within 1km)? (please leave blank if this does not apply)

Plant 1 (1)
Plant 2 (2)
Plant 3 (3)

Q10 Aside from any crops, what three plants would you rather avoid placing your hives near (within 1km)? (please leave blank if this does not apply)

Plant 1 (1)
Plant 2 (2)
Plant 3 (3)

Displayed if “Do you move your hives at different times of the year?” No Is Selected

Q6c Why do you not move your hives? (please tick all that apply)

- ❑ I do not have time to move them (1)
- ❑ I do not have the help or resources to move them (2)
- ❑ I keep them on my own property (3)
- ❑ I do not see a need to move them from where they are (4)
- ❑ To reduce the risk of my bees coming into contact with pests or diseases (5)
- ❑ Other (6)

Display if “Do you move your hives at different times of the year?” No Is Selected

Q6d Please use this space to tell us about any other reasons you have for not moving your hives

Q11 Why do you place your hives by these crops? (please tick all that apply)

	Crop 1 (1)	Crop2 (2)	Crop3 (3)
It produces good yields of honey (1)	❑	❑	❑
It produces a high value honey (2)	❑	❑	❑
It produces reliable honey yields (10)	❑	❑	❑
It is good for colony growth and survival (9)	❑	❑	❑
I have easy access to it/it just happens to be there (3)	❑	❑	❑
It is the most widely available forage at the time of the year it flowers (4)	❑	❑	❑
It is important to the sustainability of my colonies (5)	❑	❑	❑
I was recommended to place my hives near it by another beekeeper (6)	❑	❑	❑
I am asked/paid by a local farmer for placing my hives near it (7)	❑	❑	❑
I own the crops and want them to be pollinated to ensure a good yield (8)	❑	❑	❑
Other (12)	❑	❑	❑

Q11b Please use this space to tell us about any other reasons you have for placing your hives by these crops

Q12 Why do you avoid placing your hives near these crops?

	Crop 1 (1)	Crop2 (2)	Crop3 (3)
The honey yield from this crop is poor (1)	❑	❑	❑
The honey yield from this crop is too unreliable (2)	❑	❑	❑
The honey quality from this crop is too low (3)	❑	❑	❑
There are other flower resources that provide better nectar yields at that time of year (4)	❑	❑	❑
The nectar or pollen contains toxins (to bees or humans) (5)	❑	❑	❑
I believe there is a potentially high risk from pesticides (6)	❑	❑	❑
I do not receive payments for providing pollination services to this crop (7)	❑	❑	❑
I was advised not to place my hives near it by other beekeepers (8)	❑	❑	❑
Accessing this crop would involve movement to an area with disease/pest risks (9)	❑	❑	❑
I was asked not to place my hives near this crop by a farmer (10)	❑	❑	❑

Q12b Please use this space if you wish to tell us more about why you do not place your hives near these crops

Q13 Why do you place your hives by these plants? (please tick all that apply)

	Crop 1 (1)	Crop 2 (2)	Crop 3 (3)
It produces good yields of honey (1)	❑	❑	❑
It produces a high value honey (2)	❑	❑	❑
It produces reliable honey yields (10)	❑	❑	❑
It is good for colony growth and survival (11)	❑	❑	❑
I have easy access to it/it just happens to be there (3)	❑	❑	❑
It is the most widely available forage at the time of the year it flowers (4)	❑	❑	❑
It is important to the sustainability of my colonies (5)	❑	❑	❑
I was recommended to place my hives near it by another beekeeper (6)	❑	❑	❑
I am asked/paid by a local landowner for placing my hives near it (7)	❑	❑	❑
I own the land and want to ensure this plant has a stable population (8)	❑	❑	❑
Other (9)	❑	❑	❑

Q13b Please use this space to tell us about any other reasons you have for placing your hives by these plants

Q14 Why do you avoid placing your hives near these plants?

	Choice 1 (1)	Choice 2 (2)	Choice 3 (3)
The honey yield from this plant is poor (1)	❑	❑	❑
The honey yield from this plant is too unreliable (2)	❑	❑	❑
The honey quality from this plant is too low (3)	❑	❑	❑
There are other flower resources that provide better nectar yields at that time of year (4)	❑	❑	❑
The nectar or pollen contains toxins (to bees or humans) (5)	❑	❑	❑
I believe there is a potentially high risk from pesticides or other chemicals (6)	❑	❑	❑
I was asked not to place my hives near this plant by a local landowner (9)	❑	❑	❑
I was advised not to place my hives near it by other beekeepers (7)	❑	❑	❑
Accessing this plant would involve movement to an area with disease/pest risks (8)	❑	❑	❑

Q15 Are there any crops or potential forage plants that you would like to see more of in the landscapes around your hives?

Q16 Are there any factors that would encourage you to expand the number of hives you keep?

Q17 Is there anything that local farmers could do to encourage you to provide pollination services to their crops if you do not do so already?

Q18 Is there anything that policy could do to encourage you to provide pollination services to local crops?

Q19 Do you have any other comments on managing your hives for pollination services that you would like to share with us?

SUPER-B Farmers English

Cover Thank you for agreeing to participate in this survey conducted by the University of Reading. The survey should take less than 20 minutes to complete. The purpose of this study is to find out about how farmers across Europe manage pollination services to their crops. We hope the findings of this study will inform future policy on wider countryside management across Europe to help farmers maintain effective and stable pollination services. The findings will be published in a peer-reviewed academic journal, which we will endeavor to make openly available for any who are interested, and presented at beekeeping conferences. This study is funded by the EU's SUPER-B program, and has been designed, administered and will be analyzed by the University of Reading (UK).

Ethics Before we begin, we are required to explain a few details of this study. All information will be kept strictly confidential and none of the questions will allow you to be identified in any way. Should you wish to withdraw your answers from this survey at any time prior to the publication of results please call me on 0118 378 6419 or e-mail t.d.breeze@reading.ac.uk and quote the questionnaire ID below – this number is linked to your responses but the survey does not collect your personal details so it will remain anonymous. Your response will be held in our records for a period of no longer than 5 years and will not be passed on to any third parties. By participating you are consenting to these terms of data storage and use which have been approved by the University of Reading's Ethics Committee.

Q1 Please enter a number to identify this questionnaire (e.g. the date and time you are taking the survey)

Q2 Which country are you based in?

Q3 Of the insect pollinated crops you grow, what would you consider to be the three most important to your farming activities? (if you grow less than three insect pollinated crops, please leave the appropriate boxes blank. If this question is non-applicable, please leave all three boxes blank or you will be asked to answer questions that are not relevant to you).

Crop 1 (1)
Crop 2 (2)
Crop 3 (3)

Q4 Are you part of any organic farming scheme?

❍ Yes (1)
❍ No (2)

Display if: “Are you part of any organic farming scheme?” Yes Is Selected
Q4b Which organic farming scheme are you part of?

Q5 Are you part of any government or privately funded agri-environment schemes?

❍ Yes (1)
❍ No (2)

Display if “Are you part of any agri-environment schemes?” Yes Is Selected
Q5b Which government or privately funded agri-envrionment schemes are you part of?

Q6 How much do you believe the yields of these crops would decrease without any animal pollination?

_______ Crop 1 (1)
_______ Crop 2 (2)
_______ Crop 3 (3)

Q7 Do you believe the yields of any of these crops are currently lower than they could be because of insect pollination on any of your land?

	Yes (1)	No (2)
Crop 1 (1)	❍	❍
Crop 2 (2)	❍	❍
Crop 3 (3)	❍	❍

Q8 Do you own and manage honeybees for pollination services to any of your important insect pollinated crops?

	Yes (1)	No (2)
Crop 1 (1)	❍	❍
Crop 2 (2)	❍	❍
Crop 3 (3)	❍	❍

Q9 Do you hire or buy any managed insects to provide pollination services to your crops? (please tick all that apply)

	Managed Honeybees (1)	Managed Bumblebees (2)	Managed Solitary bees (3)	None (4)
Crop 1 (1)	❑	❑	❑	❑
Crop 2 (2)	❑	❑	❑	❑
Crop 3 (3)	❑	❑	❑	❑

Display if: “Do you hire or buy any managed insects to provide pollination services to your crops? (please tick all that apply)” - None Is Not Selected Or “Do you own and manage honeybees for pollination services to any of your important insect pollinated crops” - No Is Not Selected

Q10 How many of these managed pollinators do you typically use (including any honeybees you own) per hectare of your three most important insect pollinated crops?

	Honeybee Hives (1)	Bumblebee colonies (2)	Solitary bee cocoons (3)
Crop 1 (1)			
Crop 2 (2)			
Crop 3 (3)			

Display if “Do you hire or buy any managed insects to provide pollination services to your crops?“ - No Is Not Selected

Q11 If you hire or buy any managed pollinators how much do you typically spend per hive, colony or 100 cocoons?

	£ per hive hired (1)	£ per bumblebee colony (2)	£ per 100 cocoons (3)
Crop 1 (1)			
Crop 2 (2)			
Crop 3 (3)			

Q12 Do you use any following management measures to encourage pollinators in your crop fields? (please tick all that apply)

❑ Flower rich field margins (1)
❑ Avoid spraying insecticides near field edges (2)
❑ Maintain hedgerows (3)

Display if “Do you own and manage honeybees for pollination services to any of your important insect pollinated crops” - Yes Is Selected Or “Do you hire or buy any managed insects to provide pollination services to your crops? (please tick all that apply)” - Honeybees is selected

Q13 Why do you use honeybees to pollinate your crops? (please tick all that apply)

	Crop 1 (1)	Crop 2 (2)	Crop 3 (3)
They are effective pollinators of this crop (1)	❑	❑	❑
My fields are too big for wild pollinators alone to meet my pollination requirements (2)	❑	❑	❑
I was recommended to use them to pollinate this crop by another farmer (3)	❑	❑	❑
I was recommended to use them to pollinate this crop by an agronomist (4)	❑	❑	❑
I was recommended to use them to pollinate this crop by the government (5)	❑	❑	❑
I am able to get them at little or no cost (6)	❑	❑	❑
I find them easy to use (7)	❑	❑	❑
I like seeing them on my farm (8)	❑	❑	❑

Display if “Do you hire or buy any managed insects to provide pollination services to your crops? (please tick all that apply)” - Bumblebee colonies Is Selected

Q14 Why do you use bumblebees to pollinate your crops? (please tick all that apply)

	Crop 1 (1)	Crop 2 (2)	Crop 3 (3)
They are effective pollinators of this crop (1)	❑	❑	❑
My fields are too big for wild pollinators alone to meet my pollination requirements (2)	❑	❑	❑
I was recommended to use them to pollinate this crop by another farmer (3)	❑	❑	❑
I was recommended to use them to pollinate this crop by an agronomist (4)	❑	❑	❑
I was recommended to use them to pollinate this crop by the government (5)	❑	❑	❑
I am able to get them at little or no cost (6)	❑	❑	❑
I find them easy to use (7)	❑	❑	❑
I like seeing them on my farm (8)	❑	❑	❑

Display if “Do you hire or buy any managed insects to provide pollination services to your crops? (please tick all that apply)” - Solitary Bee cocoons Is Selected

Q15 Why do you use managed solitary bees to pollinate your crops? (please tick all that apply)

	Crop 1 (1)	Crop 2 (2)	Crop 3 (3)
They are the most effective pollinator of this crop (1)	❑	❑	❑
My fields are too big for wild pollinators alone to meet my pollination requirements (2)	❑	❑	❑
I was recommended to use them to pollinate this crop by another farmer (3)	❑	❑	❑
I was recommended to use them to pollinate this crop by an agronomist (4)	❑	❑	❑
I was recommended to use them to pollinate this crop by the government (5)	❑	❑	❑
I am able to get them at little or no cost (6)	❑	❑	❑
I find them easy to use (7)	❑	❑	❑
I like seeing them on my farm (8)	❑	❑	❑

Display if “Do you use any following management measures to encourage pollinators in your crop fields? (please tick all that apply)” Flower rich field margins Or Avoid spraying insecticides near field edges Or Maintain hedgerows Is Selected

Q16 Why do you use the habitat management measures indicated above? (please tick all that apply)

	Maintain flower rich field margins (1)	Avoid spraying insecticides near margins (2)	Maintain hedgerows (3)
It encourages wild pollinators that benefit my crop yields (1)	❑	❑	❑
It enhances the productivity of my crops in other ways (2)	❑	❑	❑
It encourages wildlife on my farm land (3)	❑	❑	❑
I don’t have another use for the land (4)	❑	❑	❑
It has little or no cost for me (5)	❑	❑	❑
It helps me meet my greening objectives (6)	❑	❑	❑
It helps me obtain agri-environment funding (7)	❑	❑	❑
I am required to do this as part of an organic or agri-envrionment scheme that I am part of (8)	❑	❑	❑
I was recommended to use this management by another farmer (9)	❑	❑	❑
I was recommended to use this management by an agronomist (10)	❑	❑	❑
I was recommended to use this management by the government (11)	❑	❑	❑

Q17 Do you use any other habitat management measures to encourage pollinators on your land? If so, please use this space to tell us what they are and why you use them.

Q18 On a scale of 0 to 5, with 5 being very useful and 0 being not useful at all, how useful do you believe these managed pollinators/management options are at increasing crop yields?

	Crop 1 (1)	Crop 2 (2)	Crop 3 (3)
Managed Honeybees (1)			
Managed Bumblebees (2)			
Managed Solitary bees (3)			
Field management to increase wild pollinators (4)			

Q19 Are there any crops that you grow that you do not want to be visited by pollinating insects? If there are, please use this space to tell us why.

Q20 Are there any measures you would like to take to improve pollination services to your crops that you do not currently use?

Measure 1 (1)
Measure 2 (2)
Measure 3 (3)

Q21 Which crops would you like to use these measures for?

Crop 1 (1)
Crop 2 (2)
Crop 3 (3)

Q22 What barriers are preventing you from using these measures?

	Crop 1 (1)	Crop 2 (2)	Crop 3 (3)
I do not have enough access to the expertise or equipment needed (1)	❑	❑	❑
It is too expensive for me to justify (2)	❑	❑	❑
I do not know how to manage it properly (3)	❑	❑	❑
I do not have the space available to use it (4)	❑	❑	❑
It is unavailable to me (5)	❑	❑	❑

Q23 Do you believe that there are any other barriers to adopting the measures you would like to use? If so please use this space to tell us about them.

Q24 What actions or support do you believe would help you to use these measures in your crops?

Appendix 2: Summary of respondents

Table A2-1: Summary of beekeepers by country

Country	Hobby	Professional	All
Cyprus	13	18	31
Estonia	68	36	104
Greece	97	96	193
Italy	121	75	196
Malta	28	10	38
Netherlands	172	19	191
Portugal	104	46	150
Serbia	92	42	134
Slovenia	294	26	320
UK	232	120	352
Total	1221	488	1709

Table A2-2: Average beekeeper years experience and colonies managed.

	Average of Approximately how many years have you been keeping bees?			Average of Approximately how many honeybee colonies do you presently manage?		
Country	Hobby	Professional	All	Hobby	Professional	All
Cyprus	13.15	16.50	15.10	41.54	319.72	203.06
Estonia	13.51	19.06	15.43	18.00	165.92	69.20
Greece	4.91	13.56	9.21	28.95	173.65	100.55
Italy	10.17	15.49	12.21	21.58	216.09	96.01
Malta	13.32	31.50	18.11	13.46	145.50	48.21
Netherlands	18.57	26.74	19.38	11.67	95.53	20.02
Portugal	9.58	11.87	10.29	70.71	329.85	150.18
Serbia	15.32	17.33	15.95	53.73	140.45	80.91
Slovenia	11.71	16.79	12.09	23.58	236.08	39.62
UK	13.54	25.03	17.45	8.72	139.39	53.27
Total	12.58	18.42	14.25	25.24	187.97	71.50

Table A2-3: Summary of farmers by country organised by participation in Organic and Agri-Environment Schemes (AES)

	Non-Organic farmers			Organic farmers			Total
Country	Non-AES	AES	Total	Non-AES	AES	Total	
Cyprus	26	1	27		5	5	32
Estonia	26	20	46	10	3	13	59
Greece	19	2	21				21
Italy	34	6	40	12	6	18	58
Malta	36	3	39				39
Netherlands	31		31	1		1	32
Portugal	20	8	28	15	14	29	57
Serbia	16	8	24	3	2	5	29
Slovenia	34	1	35	5	1	6	41
UK	31	22	53		5	5	58
Grand Total	273	71	344	46	36	82	426

Table A2-4: Crops used by beekeepers in each country

Crop	CYP	EST	GRC	ITA	MLT	NLD	PRT	SRB	SVN	UK	Total
Acacia			4	9							13
Almond	2		18	1			7				28
Anise			1								1
Apple	1	5	5	9		8	7	9	36	19	99
Apricot			5	2			1	1			9
Arable crops				1						1	2
Aubergine				1							1
Barley				1					3	2	6
Beans						1				1	2
Beet						2				1	3
Berries					1						1
Bilberry							2				2
Blackberry			1			1	2			8	12
Blackcurrant										1	1
Blueberry						5				2	7
Borage										25	25
Brassica			1	1			1			1	4
Buckwheat		12				1		2	67		82
Carob	3			1	4		1				9
Carrot				1		1					2
Cereal		5				4					9
Cherry	1		13	9		7	8	1	16	5	60
Chestnut			11	13			20		5		49
Chicory				1							1
Cider Apple										2	2
Citrus	4		6	7	1		3				21
Clover		33	24	7	2	2	5	1	13	12	99
Coriander	1			3							4

Crop	CYP	EST	GRC	ITA	MLT	NLD	PRT	SRB	SVN	UK	Total
Cotton			46								46
Courgette				1		1					2
Eucalyptus	3			4	1		1				9
Fabaceae spp.		1									1
Field Bean		3	1		1		1			77	83
Fodder crops						1					1
Fruit crops						25				3	28
Garden			3							4	7
Grape			2	12	1		7		19		41
Grassland		1		6		7		1		2	17
Green manure crops						1					1
Hay		1				1		7			9
Hazelnut				3			2				5
Herbaceous							1				1
Holly						1					1
Horticulture							5				5
Italian Sainfoin				6	7						13
Kiwifruit			3	1			4		1		9
Lavender	2		3	1					1	2	9
Leguminous plants							1				1
Lemon	2		1								3
Linseed										1	1
Loquat	1						1				2
Lucerne		3	2	19		3		1		1	29
Maize			12	20		14	13		54	1	114
Marrow					1						1
Melon				2	2		1				5
Mixed				3	1					3	7
Mustard						5		2	1	2	10
Oilseed Rape		25	9	11		41	6	31	35	155	313
Olive			3	4			5		1		13
Orange	16		24	3	2		4				49
Orchard			1	10	2	4	4	8		25	54
Oregano			1								1
Ornamental flowers						2				1	3
Pasture							1				1
Peach			6	3	2		1		2		14
Pear		1	2			6	2	1	2	2	16
Persimmon									1		1
Pine			9							1	10
Pistachio			1								1
Plum				2				3	1		6
Pomegranate			1								1
Poppy										1	1
Potato					1	7	7		17		32
Pumpkin					2	3		1	8		14
Radish						2					2

Crop	CYP	EST	GRC	ITA	MLT	NLD	PRT	SRB	SVN	UK	Total
Raspberry		3		1			2	2	1	2	11
Redcurrant						1					1
Rice Fields			1								1
Robinia		1	1					14	5		21
Rosehip						2					2
Rosemary			1								1
Runner Bean			1				2		1		4
Rye							1				1
Sea Buckthorn		1									1
Soft fruit				2						4	6
Squash			1				4				5
Strawberry		1			1	5	1			1	9
Strawberry Tree			2				3				5
Sunflower			17	14		2	5	65	13		116
Tangerine	1										1
Thyme	4		14	2				2		1	23
Tomato							1				1
Tulip						1					1
Urban mixed										1	1
Vegetable				5	1	1				1	8
Vetch			1								1
Watermelon				1	1						2
Wheat		2	1	8	1		1		19	8	40
Willow						1					1
Total	41	98	259	211	35	169	144	152	317	384	1810

CYP = Cyprus, EST = Estonia, GRC = Greece, ITA = Italy, MLT = Malta, NLD = Netherlands, PRT = Portugal, SRB = Serbia, SVN = Slovenia

Table A2-5: Crops avoided by beekeepers by country

Crop	CYP	EST	GRC	ITA	MLT	NLD	PRT	SRB	SVN	UK	Total
All farms										1	1
Almond			3				1				4
Apple	1		4	13			1	6	3	2	30
Apricot			1	1							2
arboriculture				1		1					2
Artichoke				1							1
Asparagus						2					2
Aubergine				1		1					2
Barley		1		2				1	2	5	11
Beans						1					1
Beet				5				7	1	4	17
Belgian Endive						1					1
Berries				2							2
Brassica									2	1	3
Buckwheat		1								1	2
Carrot						2					2
Cereal	1				2	2				6	11
Cherry			4	2				2			8
Chicory										1	1
Citrus			2					2			4
Clover		2	1								3
Cotton			44								44
Courgette				2						1	3
Crops	1			2		1		5			9
Cucumber						1					1
Daffodil						1					1
Eucalyptus				1							1
Field Bean		1									1
Fruit Crops				2		2		1		1	6
Gladiolus						1					1
GM crops										2	2
Grape			2	46	1	1	7	1	19	1	78
Grassland						4				2	6
Hazelnut				4							4
Horticulture						1	2				3
Hyacinth						1					1
Kiwifruit				1							1
Lemon	1			1							2
Lilies						1					1
Linseed										1	1
Lucerne		1		1	1			4	1		8
Maize		3	8	58		27	10	7	53	6	172
Melon			1		1		1				3
Mustard				1		1		4		1	7
Non-flowering crops										1	1

Crop	CYP	EST	GRC	ITA	MLT	NLD	PRT	SRB	SVN	UK	Total
Non-organic		1									1
Oat									1	1	2
Oilseed Rape		53	2	6	1	4		18	8	76	168
Olive	1		2	6			5				14
Onion				1							1
Orange	2		12								14
Orchard		1	5	20			6	4			36
Organic crops										1	1
Ornamental plants				2		3		1			6
Palm Trees			2								2
Pasture						1					1
Pea										1	1
Peach	1		6	2							9
Pear			3	3				1			7
Pistachio			4								4
Plum			2							1	3
Poplar				4							4
Potato	6	1		3	1	12			4	6	33
Raspberry				1				4			5
Roses			1								1
Sainfoin				1							1
Seed Plants				1				1			2
Soybean				6				3			9
Strawberry					1						1
sunflower			4	9		2	4	20	1	1	41
Sweet Potato					1						1
Tabacco			3	1				1			5
Tangerine	1		1								2
Tomato				4	2	1		1			8
Traditional crops							1				1
Treated crops			1			2		1		5	9
Tulip						2					2
Vegetable	1		2	7							10
Watermelon				1	1						2
Wheat		1		10	1			1	9	6	28
Grand Total	**16**	**66**	**588**	**600**	**13**	**581**	**452**	**412**	**963**	**1059**	**4854**

CYP = Cyprus, EST = Estonia, GRC = Greece, ITA = Italy, MLT = Malta, NLD = Netherlands, PRT = Portugal, SRB = Serbia, SVN = Slovenia. Several beekeepers named crop categories rather than specific crops (e.g. “orchard”), these responses are presented as written.

Table A2-6: Fields of each crop grown by farmers in each country

Crop	CYP	EST	GRC	ITA	MLT	NLD	PRT	SRB	SVN	UK	Total
Acacia				6							6
Almond	1			1			5				7
Apple	3	5	5	12	2	2	10	13	24	2	78
Apricot			2	5				3			10
Aubergine					5						5
Avocado	1										1
Banana	1										1
Barley		3								4	7
Beans	2	1									3
Beet		1									1
Berries		2					1				3
Bilberry		2					2				4
Blackcurrant		1									1
Blueberry		1		1		1				2	5
Brassica	4						1				5
Buckwheat		1									1
Cabbage	3										3
Cannabis		2									2
Carob	1										1
Carrot		1									1
Cattley Guava							1				1
Cereals								1			1
Cherry		1	7	10		1	3	6	7	2	37
Chestnut				5			12				17
Chinese Wolfberry							1				1
Chokeberry		1						2			3
Citrus	1			2	1		1				5
Clover		10					1		1		12
Courgette				1						1	2
Cranberry		1									1
Cucumber	6	3			2						11
Cucurbita					1						1
Currant				1					1		2
Damson	1										1
Eucalyptus				1							1
Field Bean		2			2					8	12
Forage crops							1				1
Forests							1				1
Fruits								1			1
Grain plant							1				1
Grape	2			2	1		3	3	4		15
Grass										1	1
Grassland				1							1
Hawthorn				1							1
Hay crops		1									1

Crop	CYP	EST	GRC	ITA	MLT	NLD	PRT	SRB	SVN	UK	Total
Hazelnut								1			1
Honey Clover		2									2
Horticultural crops							2				2
Italian Sainfoin				1							1
Key Lime							1				1
Kitchen garden					1						1
Kiwifruit			2	1			2		1		6
Lavender							1				1
Lemon	2										2
Lettuce	1										1
Linden Tree				1							1
Linseed										1	1
Loquat	1				1						2
Lucerne		1		3				3			7
Maize							1	5	1		7
Mandarin			1								1
Marrow	2				13						15
Melon	3			4	13		1	1			22
Oat							1			1	2
Oilseed Rape		12						3		39	54
Oleaginous Linden Tree				1							1
Olive	3			1	1		6				11
Onion	1			1			1				3
Orange	2		1	2			2				7
Orchard		6		5	1		2			1	15
Paprika								1			1
Pasture							1				1
Pea		3								3	6
Peach	1		16	1	4				5		27
Pear	2	1	1	1	1	15				1	22
Perennial Ryegrass							1				1
Persimmon									1		1
Phacelia		1									1
Plum			3	2			1	8	3		17
Pot Marigold		1									1
Potato	3						3			3	9
Pumpkin		1		2	3						6
Quince							1	2			3
Raspberry		4		2	1		3	7	7	3	27
Red Clover		4						1		1	6
Rosemary							1				1
Runner Bean							1				1
Rye							2				2
Seed Plants				1							1
Siberian Apricot									3		3
Soybean								4			4

Crop	CYP	EST	GRC	ITA	MLT	NLD	PRT	SRB	SVN	UK	Total
Squash							1				1
Stone Fruit	4				1						5
Strawberry	1	4		3	13	14			2	4	41
Sunflower								9			9
Sweet Pepper	1				3						4
Tobacco		1									1
Tomato	11	2		1	21		2				37
Tree f Heaven				1							1
Vegetables	2			2				1	1		6
Vining Pea					1					1	2
Walnut							3				3
Watermelon	8			2	4		1	2			17
Wheat		3					1	2	2	5	13
White Clover		2									2
Total Fields	**74**	**87**	**38**	**87**	**96**	**33**	**86**	**79**	**63**	**83**	**727**

CYP = Cyprus, EST = Estonia, GRC = Greece, ITA = Italy, MLT = Malta, NLD = Netherlands, PRT = Portugal, SRB = Serbia, SVN = Slovenia. Several beekeepers named crop categories rather than specific crops (e.g. “orchard”), these responses are presented as written.

Table A2-7: p-values from Pairwise Kruskal-Wallis tests of significance in differences between the number of years of beekeeping experience between countries (bold denotes significance at p<0.05)

	CYP	EST	GRC	ITA	MLT	NLD	PRT	SRB	SVN
EST	1	-	-	-	-	-	-	-	-
GRC	0.378	**0.003**	-	-	-	-	-	-	-
ITA	0.842	0.110	0.942	-	-	-	-	-	-
MLT	1	1	**0.048**	0.317	-	-	-	-	-
NLD	1	1	**<0.001**	**0.001**	1	-	-	-	-
PRT	0.661	**0.038**	1	1	0.167	**<0.001**	-	-	-
SRB	1	1	**<0.001**	**0.005**	1	1	**0.001**	-	-
SVN	0.962	0.301	0.383	0.998	0.554	**0.004**	0.924	**0.022**	-
UK	0.998	0.991	**<0.001**	**<0.001**	1	1	**<0.001**	1	**<0.001**

CYP = Cyprus, EST = Estonia, GRC = Greece, ITA = Italy, MLT = Malta, NLD = Netherlands, PRT = Portugal, SRB = Serbia, SVN = Slovenia

Table A2-8: p-values from Pairwise Kruskal-Wallis tests of significance in differences between the number of hives kept between countries

	CYP	EST	GRC	ITA	MLT	NLD	PRT	SRB	SVN
EST	**0.001**	-	-	-	-	-	-	-	-
GRC	0.593	**0.002**	-	-	-	-	-	-	-
ITA	**0.005**	0.986	**0.016**	-	-	-	-	-	-
MLT	**<0.001**	0.986	**0.004**	0.663	-	-	-	-	-
NLD	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.061	-	-	-	-
PRT	0.561	**0.008**	1	0.054	**0.007**	**<0.001**	-	-	-
SRB	0.816	**0.001**	1	**0.008**	**0.002**	**<0.001**	1	-	-
SVN	**<0.001**	0.349	**<0.001**	**0.001**	1	**<0.001**	**<0.001**	**<0.001**	-
UK	**<0.001**	**0.007**	**<0.001**	**<0.001**	0.964	**0.007**	**<0.001**	**<0.001**	0.618

CYP = Cyprus, EST = Estonia, GRC = Greece, ITA = Italy, MLT = Malta, NLD = Netherlands, PRT = Portugal, SRB = Serbia, SVN = Slovenia

Table A2-9 Comparison of number of beekeepers and colonies per beekeeper between the sample and Chauzaut et al. (2013)

Country	N beekeepers	Total beekeepers	% Professional	2010 % professional	Hives/ beekeeper (2010)	Hives/ beekeeper (sample)
CYP	31	552	58%	9%	203.1	72.6
EST	104	42,000	35%	1%	69.2	13.6
GRC	193	1500000	50%	39.5%	100.5	75
ITA	196	1127000	38%	10%	96.0	16.1
MLT	38	Unknown	26%		48.2	
NLD	191	80000	10%	1%	20.0	10
PRT	150	580065	31%	3%	150.2	33.6
SRB	134	Unknown	31%		80.9	
SVN	320	156178	8%		39.6	17.2
UK	352	200000	34%	1%	53.2	5

Table A2-10 proportion of Organic Farmers in the Sample vs the national % of Organic Farmers in 2016

	Organic Farmers	
	Sample	2016
Cyp	16%	3%
Est	22%	11%
Grc	0%	3%
Ita	31%	6%
Mlt	0%	0%
Nld	3%	3%
Prt	51%	2%
Slo	17%	2%
Srb	15%	
UK	9%	2%

Sample = the % of Organic farmers in the sample, 2016 = The % of Organic farmers in the country for 2016 (closest available data – Eurostat, 2019)

Appendix 3 – Levels of perceived pollination service deficit and impact in respondent farmers

Throughout, pollination service deficit is defined as a partial or total shortfall in yield due to inadequate pollination service provision to the crop.

Table A3-1. Crop-specific incidence of perceived pollination service deficit and the scale of perceived yield loss in the absence of pollination services

	No Deficit	Deficit	Total	% no deficit	% Deficit	Yield Loss %
Acacia	2	2	6	33	33	59.75
Almond	1	5	7	14	71	44.86
Apple	38	29	78	49	37	59.34
Apricot	1	9	10	10	90	58.00
Aubergine	2	3	5	40	60	72.00
Avocado		1	1	0	100	40.00
Banana		1	1	0	100	90.00
Barley	3	2	7	43	29	50.83
Beans		3	3	0	100	70.00
Beet		1	1	0	100	39.00
Berries	3		3	100	0	81.67
Bilberry	2	2	4	50	50	63.00
Blackcurrant	1		1	100	0	20.00
Blueberry	2	2	5	40	40	55.00
Brassica	3		5	60	0	35.00
Buckwheat		1	1	0	100	100.00
Cabbage	2		3	67	0	20.00
Cannabis	1	1	2	50	50	75.00
Carob		1	1	0	100	92.00
Carrot		1	1	0	100	40.00
Cattley guava	1		1	100	0	31.00
Cereals	1		1	100	0	50.00
Cherry	11	20	37	30	54	64.19
Chestnut	7	8	17	41	47	37.44
Chinese Wolfberry		1	1	0	100	70.00
Chokeberry	1	1	3	33	33	57.00
Citrus	2	2	5	40	40	63.75
Clover	11	1	12	92	8	61.08
Courgette	1	1	2	50	50	72.50
Cranberry	1		1	100	0	3.00
Cucumber	3	7	11	27	64	74.10
Cucurbita	1		1	100	0	99.00
Currant	1	1	2	50	50	50.50
Damson			1	0	0	80.00
Eucalyptus		1	1	0	100	90.00
Field bean	11	1	12	92	8	54.33
Forage crops	1		1	100	0	91.00
Forests		1	1	0	100	30.00
Fruits	1		1	100	0	81.00

	No Deficit	Deficit	Total	% no deficit	% Deficit	Yield Loss %
Grain plant		1	1	0	100	52.00
Grape	8	6	15	53	40	51.15
Grass	1		1	100	0	50.00
Grassland	1		1	100	0	32.00
Hawthorn		1	1	0	100	81.00
Hay crops	1		1	100	0	50.00
Hazelnut	1		1	100	0	30.00
Honey clover	2		2	100	0	80.00
Horticultural crops		2	2	0	100	53.00
Italian Sainfoin			1	0	0	
Key Lime	1		1	100	0	33.00
Kitchen garden	1		1	100	0	70.00
Kiwifruit	1	4	6	17	67	78.60
Lavender	1		1	100	0	
Lemon	1	1	2	50	50	45.00
Lettuce	1		1	100	0	
Linden tree	1		1	100	0	60.00
Linseed	1		1	100	0	44.00
Loquat	1	1	2	50	50	54.00
Lucerne	2	4	7	29	57	63.50
Maize	5	2	7	71	29	34.33
Mandarin		1	1	0	100	50.00
Marrow	8	7	15	53	47	63.50
Melon	5	17	22	23	77	71.14
Oat	1	1	2	50	50	59.50
Oilseed rape	41	9	54	76	17	44.96
Oleaginous crops	1		1	100	0	37.00
Olive	1	9	11	9	82	42.90
Onion	2		3	67	0	20.00
Orange	1	6	7	14	86	72.71
Orchard	5	8	15	33	53	69.62
paprika		1	1	0	100	55.00
Pasture	1		1	100	0	73.00
Pea	5		6	83	0	73.00
Peach	8	16	27	30	59	49.42
Pear	12	7	22	55	32	30.55
Perennial Ryegrass	1		1	100	0	80.00
Persimmon			1	0	0	31.00
Phacelia	1		1	100	0	80.00
Plum	6	10	17	35	59	65.00
Pot marigold	1		1	100	0	69.00
Potato	6	2	9	67	22	32.83
Pumpkin		5	6	0	83	50.50
Quince	2	1	3	67	33	60.67
Raspberry	18	9	27	67	33	62.15

	No Deficit	Deficit	Total	% no deficit	% Deficit	Yield Loss %
Red Clover	2	4	6	33	67	71.50
Rosemary	1		1	100	0	46.00
Runner Bean			1	0	0	90.00
Rye		2	2	0	100	69.00
Seed plants		1	1	0	100	91.00
Siberian apricot	1	2	3	33	67	82.50
Soybean	3	1	4	75	25	52.75
Squash	1		1	100	0	30.00
Stone fruit	2	3	5	40	60	76.00
Strawberry	25	15	41	61	37	34.26
Sunflower	2	6	9	22	67	48.75
Sweet pepper		4	4	0	100	65.00
Tobacco		1	1	0	100	64.00
Tomato	11	23	37	30	62	72.67
Tree of heaven	1		1	100	0	92.00
Vegetables	3	3	6	50	50	55.33
Vining pea	2		2	100	0	52.50
Walnut	1	2	3	33	67	30.00
Watermelon	6	11	17	35	65	68.19
Wheat	9	2	13	69	15	44.92
White Clover	1	1	2	50	50	100.00

No deficit = number of farmers who indicated that they are not suffering pollination service deficits. Deficits = the number of farmers who indicate that they are suffering pollination service deficits. Total = the total number of farmers who grow the crop. % no deficit = the percentage of farmers who do not perceive pollination service deficits. % deficit = the % of farmers who do perceive pollination service deficits. Note that these values may not total 100% if a farmer named a crop but did not indicate whether or not they believed there was a deficit. Yield loss % = the average % yield loss that all farmers expect the crop to experience in the absence of pollinators.

Table A2-2 Country specific number of farmers perceiving pollination service deficit

Crop	CYP	EST	GRC	ITA	MLT	NLD	PRT	SVN	SRB	UK	Total
Acacia				2							2
Almond	1			1			3				5
Apple	2	2	3	2		1	7	3	9		29
Apricot			2	5					2		9
Aubergine					3						3
Avocado	1										1
Banana	1										1
barley		0								2	2
Beans	2	1									3
Beet		1									1
Berries		0					0				0
Bilberry		1					1				2
Blackcurrant		0									0
Blueberry				0		1				1	2
Brassica	0										0
Buckwheat		1									1
Cabbage	0										0
Cannabis		1									1
Carob	1										1
Carrot		1									1
Cattley Guava							0				0
cereals									0		0
Cherry		0	6	5			2	3	4	0	20
Chestnut				1			7				8
Chinese Wolfberry							1				1
Chokeberry		0							1		1
Citrus	1			0	1		0				2
Clover		1					0	0			1
Courgette				0						1	1
Cranberry		0									0
Cucumber	5	1			1						7
Cucurbita					0						0
Currant				1				0			1
Damson											
Eucalyptus				1							1
Field Bean		0			0					1	1
Forage crops							0				0
Forests							1				1
Fruits									0		0
Grain plant							1				1
Grape	1			1	0		1	1	2		6
grass										0	0
Grassland				0							0

Crop	CYP	EST	GRC	ITA	MLT	NLD	PRT	SVN	SRB	UK	Total
Hawthorn				1							1
Hay crops		0									0
hazelnut									0		0
Honey Clover		0									0
Horticultural crops							2				2
Italian Sainfoin											
Key Lime							0				0
Kitchen garden					0						0
kiwifruit			2	1			1	0			4
Lavender							0				0
Lemon	1										1
Lettuce	0										0
Linden tree				0							0
Linseed										0	0
Loquat	0				1						1
Lucerne		0		1					3		4
maize							1	0	1		2
Mandarin			1								1
Marrow	1				6						7
Melon	3			3	9		1		1		17
Oat							1			0	1
Oilseed Rape		2							2	5	9
Oleaginous crops				0							0
Olive	3			1	0		5				9
Onion	0						0				0
Orange	1		1	2			2				6
Orchard		3		2			2			1	8
paprika									1		1
Pasture							0				0
Pea		0								0	0
Peach			14	1	1			0			16
Pear	0	1	1		1	4				0	7
Perennial Ryegrass							0				0
Persimmon											
Phacelia		0									0
Plum			3	0			1	1	5		10
Pot Marigold		0									0
Potato	0						2			0	2
Pumpkin		1		1	3						5
Quince							0		1		1
Raspberry		0		1	0		1	1	4	2	9
Red Clover		3							1	0	4
Rosemerry							0				0
Runner Bean											
Rye							2				2

Crop	Cyp	Est	Grc	Ita	Mlt	Nld	Prt	Svn	Srb	UK	Total
Seed plants				1							1
Siberian Apricot								2			2
Soybean									1		1
Squash							0				0
Stone fruit	3				0						3
Strawberry	1	1		1	6	3		0		3	15
Sunflower									6		6
Sweet Pepper	1				3						4
Tobacco		1									1
Tomato	9			1	13		0				23
Tree of Heaven				0							0
vegetables	1			1				1	0		3
Vining pea					0					0	0
Walnut							2				2
Watermelon	7			1	0		1		2		11
Wheat		0					1	0	0	1	2
White Clover		1									1
Total	46	23	33	38	48	9	49	12	46	17	321

Cyp = Cyprus, Est = Estonia, Grc = Greece, Ita = Italy, Mlt = Malta, Prt = Portugal, Svn = Slovenia, Srb = Serbia, UK = United Kingdom. Blank cells indicate no farmers grew this crop, zeroes indicated that no farmers who grew this crop perceived a deficit

Appendix 4 – Use of managed pollinators

This appendix covers the use of each pollinator in the fields of respondent farmer. Note that responses are given on a per field basis (i.e. per crop named) so if a farmer used honeybees for two different crops they are counted twice etc. Own Honeybees are assumed to be applied to all fields they owned.

Table A4-1: Number of fields where farmers use different managed pollinators

Country	Own HB	Hire HB	Hire BB	Hire SB
Cyprus	64	6	5	0
Estonia	81	10	6	3
Greece	38	4	5	0
Italy	60	12	8	2
Malta	90	1	14	0
Netherlands	30	15	1	1
Portugal	77	17	8	1
Serbia	70	20	1	11
Slovenia	56	5	0	0
UK	7	22	7	3
Total	574	113	56	22

Own HB = number of fields where farmers use honeybee colonies they own. Hire HB = number of fields where farmers use rented honeybee colonies. Hire BB = number of fields where farmers use rented bumblebee colonies. Hire SB = number of fields where farmers use rented solitary bees.

Table A3-2: Hired managed pollinators (excluding owned honeybees) by crop

Crop	Honeybees	Bumblebees	Solitary Bees
Acacia	1		
Almond	2		
Apple	12		2
Apricot	2	3	
Aubergine		1	
Avocado			
Banana			
Barley			
Beans			
Beet			
Berries	1	1	
Bilberry	4	2	
Blackcurrant			
Blueberry	1	3	2
Brassica		1	
Buckwheat			
Cabbage			
Cannabis	1		
Carob			
Carrot			
Cattley Guava			
cereals	1		
Cherry	1	3	4
Chestnut	2		
Chinese Wolfberry	1		
Chokeberry			2
Citrus	2		
Clover			
Courgette			
Cranberry	1		
Cucumber	3	3	
Cucurbita	1		
Currant			
Damson			
Eucalyptus	1		
Field Bean	2		
Forage crops			
Forests	1		
Fruits	1		
Grain plant			
Grape	4		
Grass			
Grassland			
Hawthorn			
Hay crops			

Crop	Honeybees	Bumblebees	Solitary Bees
Hazelnut	1		
Honey Clover			
Horticultural crops	1		
Italian Sainfoin			
Key Lime			
Kitchen garden			
kiwifruit	1	2	1
Lavender			
Lemon	1		
Lettuce			
Linden tree			
Linseed			
Loquat		1	
Lucerne	1	1	2
Maize			
Mandarin			
Marrow			
Melon		2	
Oat			
Oilseed Rape	12		
Oleaginous crops			1
Olive			
Onion			
Orange	3		
Orchard	4	2	
paprika	1		
Pasture			
Pea	1		
Peach	4	1	
Pear	11	1	
Perennial Ryegrass			
Persimmon			
Phacelia			
Plum	3		1
Pot Marigold			
Potato			
Pumpkin	1		
quince			
Raspberry	4	4	2
Red Clover	2	1	1
Rosemary			
Runner Bean		1	
Rye			
Seed plants	1		
Siberian Apricot			
Soybean			
Squash			

Crop	Honeybees	Bumblebees	Solitary Bees
Stone fruit			
Strawberry	3	10	1
Sunflower	3		
Sweet Pepper			
Tobacco			
Tomato	2	10	
Tree of Heaven			
vegetables	3	1	
Vining pea	1		
Walnut			
Watermelon	1		
Wheat	1		1
White Clover	1	1	1
Grand Total	**113**	**56**	**22**

Several beekeepers named crop categories rather than specific crops (e.g. “orchard”), these responses are presented as written. Blank cells indicate that no farmers used these managed pollinators for the crop.

Appendix 5: Farmers use of Agri-Environment Measures

This appendix covers the reasons that farmers used each of the three agri-environment schemes. Note that the % values only apply to the % of farmers who selected that measure, not the whole sample.

Table A5.1. – Farmer reasons for using each of the common agri-environment schemes in major crops

	Flowered margins (% of farmers)	Avoid spraying near margins (% of farmers)	Hedgerows (% of farmers)
Enhances pollination-based yield	27%	19%	22%
Enhances yield in other ways	88%	70%	60%
Encourages wildlife	55%	35%	36%
Available spare land	69%	46%	56%
Low costs	36%	17%	17%
Required for greening payments	54%	40%	38%
Mandatory for agri-environment or organic scheme access	58%	32%	37%
Mandatory for agri-environment or organic scheme payments	29%	15%	17%
Farmer Recommendation	16%	13%	7%
Agronomist Recommendation	14%	8%	5%
Government Recommendation	30%	25%	13%

Flowered margins: Maintain flower rich field margins, Avoid spraying: Avoid spraying insecticides near margins. Results are a percentage of fields where farmers used each measure.

Table A4.2. Number of instances of each reason for using flower rich field margins, based on the most commonly grown crops

Crop	Apple	Cherry	Chestnut	Melon	Oilseed Rape	Peach	Pear	Plum	Raspberry	Strawberry	Tomato	Watermelon
N	78	37	17	22	54	27	22	17	27	41	37	17
Enhances pollination and yield	9	1			8		1	1	6	3	3	
Enhances yield in other ways	23	13	2	3	15	4	6	4	15	12	9	2
Encourages wildlife	17	8	3	1	11	4	1	3	10	4	2	1
Spare land	17	8	3	2	16	4	4	5	13	7	1	1
Low costs	9	2	2	3	6	1	1	2	8	4	4	
Greening requirements	21	6	2		8	4	2	4	11	4	1	1
Scheme Access	14	5	3		20	4		5	11	5		1
Required for AES	3	3	1		18		1	1	3	3	1	
Farmer Recommendation	4	1	2		6			1	3		2	
Agronomist Recommendation	2	2	2		1			2	3	1	3	
Government Recommendation	9	5	2	1	4	1		3	5	3	1	1

N = total number of growers growing this crop.

Table A4.3. Number of instances of each reason to use lower insecticide use on field margins, based on the most commonly grown crops

Crop	Apple	Cherry	Chestnut	Melon	Oilseed Rape	Peach	Pear	Plum	Raspberry	Strawberry	Tomato	Watermelon
N	78	37	17	22	54	27	22	17	27	41	37	17
Enhances pollination and yield	9	1	2	2	11		2		3	4	6	6
Enhances yield in other ways	32	19	5	7	24	15	3	11	19	12	12	8
Encourages wildlife	15	8	3	6	11	7	1	5	12	4	6	5
Spare land	19	11	5	6	18	8	3	7	13	8	6	5
Low costs	6	1	2	3	4	1		1	6	5	8	3
Greening requirements	18	7	4	6	19	9	1	6	8	6	7	4
Scheme Access	17	9	3	1	15	6	1	5	8	6	4	1
Required for AES	5	3	5		12	1	1		4	3	2	
Farmer Recommendation	8	2	5	1	8				1		3	2
Agronomist Recommendation	5	1	2			2		1	4	2	3	
Government Recommendation	10	7	6	2	14	10		3	2	2	2	2

N = total number of growers growing this crop.

Table 4-4. Number of instances of each reason for hedgerows, based on the most commonly grown crops

Crop	Apple	Cherry	Chestnut	Melon	Oilseed Rape	Peach	Pear	Plum	Raspberry	Strawberry	Tomato	Watermelon
N	78	37	17	22	54	27	22	17	27	41	37	17
Enhances pollination and yield	9			1	9	1	2		6	3	4	2
Enhances yield in other ways	18	6	5	4	25	7	3	3	11	7	6	5
Encourages wildlife	8	4	4	2	15	4	1		10	3	7	2
Spare land	15	7	3	3	30	5	1	4	12	5	5	3
Low costs	4		3	2	5	1			3	3	5	2
Greening requirements	16	5	3	1	14	6	1	3	8	3	3	1
Scheme Access	13	5	2		18	4		3	12	4	1	
Required for AES	2	3	1		14	1	1		2	3	2	
Farmer Recommendation	2	1	1		7						1	
Agronomist Recommendation	1		1			2		1	3		1	
Government Recommendation	4	2	2	1	7	3			1	1		1

N = total number of growers growing this crop.

Appendix 6 – Farmers perceived efficiency of different pollination service provisions

The efficiency of each provision measure in providing pollination services was posed on a 0 to 5 scale, with 0 being not at all effective to 5 being very effective.

Table A6-1. Median perceived efficiency of pollination service provisions to specific crops

Crop	Managed Honeybees	Managed Bumblebees	Managed Solitary bees	Agri-Environment Measures
Apple	5	4	4	4
Cherry	5	4	3	3
Chestnut	4	1.5	2	4
Melon	4	4.5	3	3
Oilseed Rape	4	3	2	3
Peach	5	3	3.5	4
Pear	4	3	4.5	4
Plum	4	3	3	3
Raspberry	5	5	4	4
Strawberry	4	4	2.5	3
Tomato	5	5	4	4
Watermelon	5	5	5	5